

*Kinetic Friction of Non-Coalescing
and Non-Wetting Drops*

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Final Report

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Summary

This project has focused on the experimental determination of the frictional forces associated with noncoalescing and nonwetting systems. In particular, the focus has been on friction associated with an isothermal nonwetting droplet sliding on a solid surface. The nonwetting phenomenon is driven by the establishment of a thin (of order microns in thickness) layer of lubricating gas that is swept by viscous action into the space between the liquid and solid, preventing them from coming into contact. The mechanism has been described in the review article by Neitzel & Dell'Aversana (2002). The work performed under this NASA GSRP sponsorship extends work done by Dell'Aversana & Neitzel (2004) on the load-carrying capacities of *thermocapillary* nonwetting droplets for a given relative displacement of the two surfaces in question.

Research Accomplishments

The work on this project has focused on the design and fabrication of an experimental apparatus that will permit the direct measurement of the frictional force generated by a nonwetting drop sliding on a surface. The basic design utilizing a rotating disk has been patterned after the apparatus employed by Neitzel & Dell'Aversana (2002) for their preliminary studies employing interferometry to study the shape of the lubricating film. The basic setup is shown below in Fig. 1

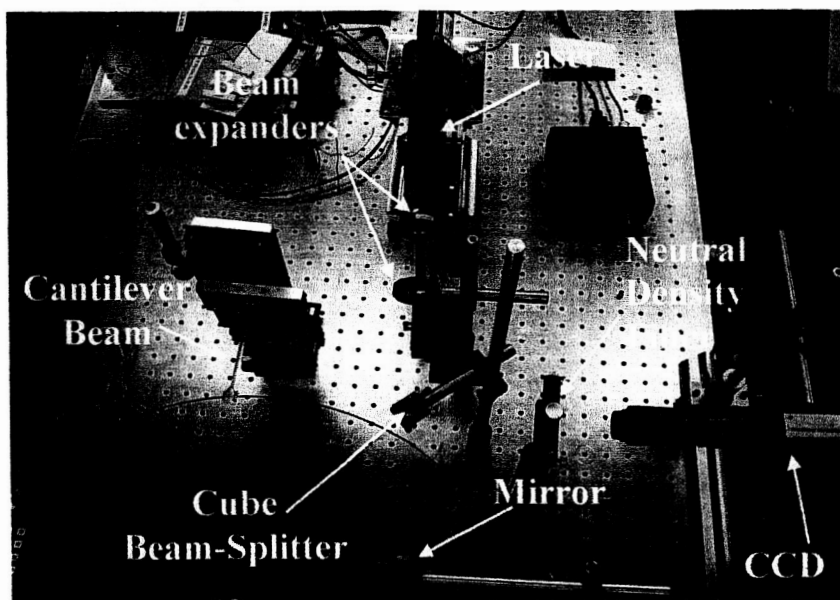


Figure 1: Experimental Setup

A liquid droplet is pinned to a support attached to a micro-machined cantilever beam which, through a vertical translation stage, allows the droplet to be pressed downward

against a rotating glass disk. The upper surface of the disk is coated with a transparent metallic film, permitting this surface to be electrically grounded through the motor. This is necessary to prevent wetting due to electrostatic effects. The frictional force is to be determined by measuring the deflection of the cantilever beam to which the droplet is attached and the calibration of this deflection under known load. The deflection measurement itself is made by employing a Michelson interferometer, necessitating the optical components shown in Fig. 1.

Of concern is the fact that the expected (on the basis of preliminary calculations) frictional force is of the same order of magnitude as the drag force exerted on the droplet *support* by the rotating flow in the Ekman boundary layer associated with the rotating disk. Consequently, significant effort has gone into the design of a “drag shield” to minimize this component of the force. This work has been summarized in earlier progress reports and will not be repeated here.

Work performed during the past year has been primarily devoted to fine-tuning issues that have arisen with the experimental setup. For example, it has been observed that nonwetting could not be maintained for long periods of time due to the fact that the rotating glass disk experienced a slight “wobble”—vertical displacements of $\pm 50\mu\text{m}$ were observed. To compensate for this, a system was designed that enables the drop support to move vertically on a linear translating stage, tracking the motion of the glass surface (see Figs. 2a and 2b). As a result, the gap between the surface of the drop and the glass remains constant.

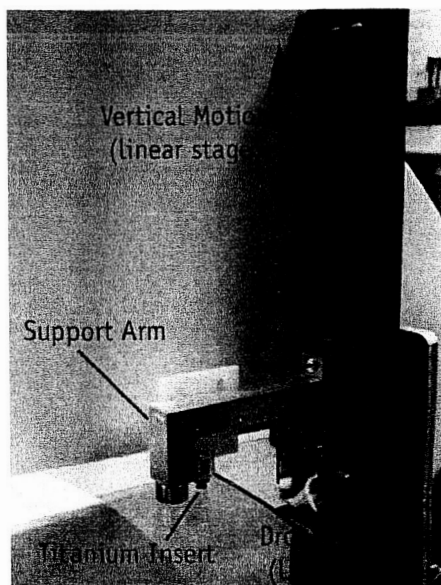


Figure 2a: Photograph of supporting arm

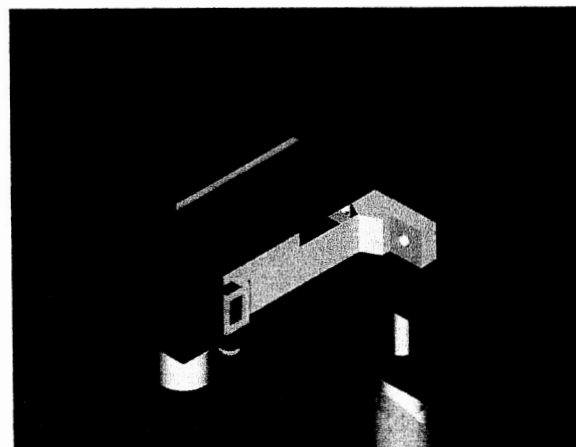


Figure 2b: CAD rendering of supporting arm

As described above, a key component of the experimental setup is the Michelson interferometer being implemented to measure the small displacements of the drop caused by the estimated $10\mu N$ lubrication force. A schematic of this interferometer is shown in Fig. 3 below.

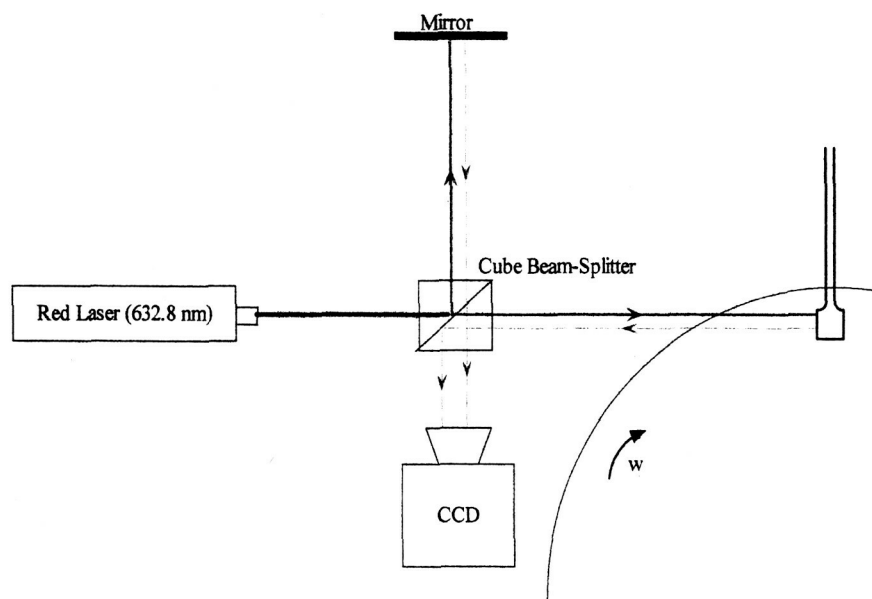


Figure 3: Schematic of Michelson Interferometry

A laser beam passes through a cube beam-splitter; one ray travels to a stationary mirror and the other to the cantilever beam. The reflected rays are sent towards a CCD camera. When the two rays join they create an interference pattern. Any difference in path length traveled by the two rays results in a change in the interference pattern. Thus, any small displacement of the cantilever due to the frictional force between the drop and the rotating glass will result in a change in the interference pattern created.

Problems have been encountered with the quality of the reflection off the cantilever beam. The cantilevers have been fabricated previously using plastic materials (Cibatool SL 7510) in a stereolithography machine as small as the technique will allow. Fabrication out of plastic has several advantages such as a beam with a very low flexural modulus. However, the plastic material is non-reflective and thus unsuitable without modification for Michelson interferometry. Attempts were made to coat the surface, however, because of the poor surface finish, the incident laser beam completely scatters off the cantilever instead of reflecting. As an alternative, the cantilevers have been redesigned to have a cavity into which an insert of a different material can be pressure fitted (see Fig. 2). Time has been invested into learning about surface finishes and polishing techniques in order to obtain the best reflective surface on the inserts. At the present time, inserts made out of Titanium ASTM-B348-CP2, polished using a tumbling process at Finishing Technologies Inc., MN are being tested.

Future Work

This project will be continued as part of a NASA grant entitled Novel Applications of Permanent Nonwetting, to begin early in 2005. The final design modifications to the experimental apparatus will be made, the cantilever calibrated, and measurements of frictional forces performed. Knowledge of these frictional forces, in particular, as a function of the relative displacement of the droplet on the surface, are critical to the proper design of a proposed "lab-on-a-chip" application of permanent nonwetting to be accomplished under the new project.

References Cited

- Dell'Aversana P, Neitzel GP. 2004. Behavior of noncoalescing and nonwetting drops in stable and marginally stable states. *Experiments in Fluids* 36: 299-308
- Neitzel GP, Dell'Aversana P. 2002. Noncoalescence and nonwetting behavior of liquids. *Annual Review of Fluid Mechanics* 34: 267-89